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Data acquisition system for soil and air data monitoring using LoRA technology

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Abstract. This work explores the application of LoRA (Long Range) technology, which allows for the development of low-cost IoT systems. It consists of developing an IoT system for acquiring information about weather conditions (peripheral towers for monitoring both air and soil quality). The various sensor elements send information through LoRA technology to a gateway located at a central point (main tower) in relation to the monitoring area. This information is sent to a database where it is stored and processed for presentation in an application developed for this purpose. The study focuses on identifying suitable solutions in relation to the autonomy of the power system (batteries) and regarding the optimized frequency for sending data from sensors using LoRA technology. For this purpose, a triangulation system was designed consisting of two peripheral towers and a main tower. Two peripheral tow-

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ers were deployed to transmit data using LoRa to a single main tower, at intervals of 15 seconds, transmitting data about soil temperature and humidity for 58 hours. Regarding the choice of batteries, it was found that the best results for a sending frequency of six sets of data per hour were achieved with LiPo 3.7 V 1350 mA batteries. Data from the two peripheral towers were sent to the main tower at the frequency of 868 MHz, respecting the maximum transmission power. A Web App, using technologies such as JavaScript, HTML, and CSS, was developed. It allows the visualisation of real-time variations in soil humidity using a line graph. It is also possible to observe the current value using a gauge chart with relevant colours, in addition to making it possible to use a time scale to be adjusted, enabling the visualization of a specific time interval. To overcome data loss issues, synchronization between the peripheral towers and the main tower was achieved using an acknowledgment frame (ACK Frame) protocol: the main tower sends an ACK frame only when reception of the data is successful. The success rate of the data transmitted was 100%. Although between 6% and 7.4% of the transmitted frames needed to be resent by the peripheral towers, this solution for overcoming data loss improves the potential successful application of LoRa technology in soil and air monitoring systems.

Keywords: Agriculture IoT; Farm automation; Smart sensor.

1. Introduction

The Internet of Things (IoT) refers to a vast network of interconnected devices, machines, and sensors that can communicate and share data with each other via the internet. IoT systems are designed to collect, process, and analyse data from various sources, providing valuable insights into various aspects of our daily lives, such as energy consumption, traffic patterns, and health monitoring [1].

The applications of IoT systems are vast and range from consumer products, such as smart home devices, to industrial applications, such as predictive maintenance in manufacturing [2–6]. In the healthcare industry, IoT devices can be used to monitor patient health remotely, enabling doctors to provide personalized care and reduce the need for in-person visits. In the transportation industry, IoT sensors can track traffic patterns, predict congestion, and optimize routes, reducing travel time and fuel consumption.

As IoT systems become more widespread, concerns around data privacy and security have become more prevalent. IoT devices can collect a vast amount of personal data, and as such, it is essential to ensure that data is collected, stored, and processed in a secure manner to protect against unauthorized access and breaches [7–9].

LoRa (Long Range) is a wireless communication protocol specifically designed for low-power wide area networks (LPWAN) to connect devices to the Internet of Things (IoT). It is an emerging technology that has been gaining popularity among developers and manufacturers for the development of low-cost IoT systems that require long-range and low-power wireless connectivity. Its chirp spread spectrum modulation enables it to achieve long-range communication at low power consumption. LoRa is also known for its excellent penetration through walls and other obstacles, which makes it suitable for indoor and outdoor use cases. It operates in the unlicensed spectrum, which means that it can be used by anyone without needing a license or paying any fees. This reduces the cost of deploying and maintaining IoT networks, making it an attractive option for businesses and organizations [4].

One of the key benefits of LoRa technology is its ability to support large-scale IoT deployments. LoRaWAN (Long Range Wide Area Network) is a standard that defines the communication protocol and system architecture for LoRa-based networks. It provides a secure and reliable way to connect millions of devices to the cloud, enabling businesses to collect and analyse data from various sources in real-time. This can lead to significant improvements in efficiency, productivity, and cost savings across many industries, such as agriculture, transportation, logistics, and smart cities [10].

In conclusion, LoRa technology offers a compelling solution for the development of low-cost IoT systems that require long-range and low-power wireless connectivity. Its ability to support large-scale IoT deployments, low cost, excellent penetration, and low power consumption make it an attractive option for businesses and organizations looking to leverage IoT for competitive advantage [11].

2. IoT Systems using LoRa technology

There are many real-world examples of LoRa technology being used in a wide range of IoT applications.

One current application of LoRaWAN-based air quality monitoring is in smart cities. Cities around the world are deploying LoRaWAN-based sensors in public areas to monitor air quality and provide citizens with real-time updates. The data collected from these sensors can help city officials identify areas with high pollution levels and take necessary steps to mitigate the issue. Additionally, this information can be used to inform citizens of potential health risks associated with air pollution and encourage them to take appropriate precautions [2].

Another application of LoRaWAN-based air quality monitoring is in industrial settings [3]. Many industries, such as manufacturing and construction, produce high levels of air pollution that can be harmful to workers' health. LoRaWAN-based sensors can be deployed in these environments to continuously monitor air quality and alert workers when pollution levels reach dangerous levels.

LoRa technology is being used in smart agriculture to improve crop yield and reduce water usage [10, 12]. In this application, farmers install LoRa-enabled soil moisture sensors in their fields that transmit data wirelessly to a gateway, which sends the data to the cloud. Farmers can access the data from the cloud to monitor soil moisture levels, temperature, and humidity, enabling them to make data-driven decisions about irrigation and fertilization.

LoRa technology is also being used in smart parking systems to help drivers find available parking spaces quickly and easily [6, 13]. In this application, sensors are installed in individual parking spaces that detect whether the space is occupied or vacant. The sensors transmit this data wirelessly to a gateway, which sends the data to the cloud. Drivers can access real-time information about available parking spaces through a smartphone app or other digital displays. This reduces the time and frustration associated with finding a parking spot and can help reduce traffic congestion and emissions from vehicles circling in search of parking [6].

LoRaWAN-based IoT systems are being used for outdoor air quality monitoring, enabling real-time monitoring of air quality in various locations. This technology uses low-power, long-range communication networks to send data from sensors to a central hub, where it is processed and analysed [14, 15].

In conclusion, LoRaWAN-based IoT systems are being used for outdoor air quality monitoring in various applications, including smart cities, industrial settings, and agriculture. This technology offers a cost-effective and reliable solution for real-time air quality monitoring, enabling individuals and organizations to take necessary actions to protect human health and the environment.

Nevertheless, as discussed in [16], collisions resulting in data loss are an issue encountered in the deployment of LoRa applications, especially in networks containing many devices and having wide coverage areas. For this reason, in addition to confirming the potential of LoRa technology for application in soil and air monitoring, this paper addresses the issue of data loss. While some complex solutions have been proposed for minimising such data loss [16], it is proposed that the introduction of an ACK frame protocol may provide a significant contribution to addressing such problems.

3. Data acquisition and monitoring system

The developed system consists of a hardware and software sub-systems comprising peripheral towers (PT) for acquiring soil-related variables; a main tower (MT) for monitoring air-related variables and serving as the gateway for all information; a server for data storage and analysis; and, finally, an application for data querying and monitoring.

The MT serves as the gateway for the data acquisition system. It also includes a weather station that provides information about atmospheric pressure, air temperature and humidity, wind direction and speed, rainfall, as well as other optional sensors, such as CO2, O3, PM2.5, PM10, CH4, noise, NO2, and SO2, which provide information about air quality. The data is sent via the internet to a remote server. Data are stored, statistically processed, and presented in a user-friendly application for different users.

Each PT consists of soil temperature and humidity sensors placed at three depth levels (surface, intermediate level, and deep level) according to the type of crop. These sensors are connected to a data acquisition board supervised by a microcontroller with communication capabilities to the MT via a wireless network (LoRa). As far as batteries are concerned, it was found that the best results for a sending frequency of six sets of data per hour were achieved with LiPo 3.7 V 1350 mA batteries. As for the power source (battery) of each PT, it is charged using renewable energy, specifically, a 20 W solar panel. Concerning the sending of information, data from the two PTs were sent to the MT at the frequency of 868 MHz, respecting the maximum transmission power.

The focus of this work is on the utilization of LoRa technology, which allows for an approach independent of telecommunications operators and is conducive to the research and development of IoT systems. In this regard, the communication between the PTs and the MT will be highlighted. Figure 1 shows the practical implementation of the developed system. The presentation of data in user-friendly applications was also addressed.

With the purpose of testing and evaluating the communication capability of LoRa technology, a range test was conducted using two SX1276 communication modules (transmitter and receiver). The method used in conducting this test involved transmitting packets every five seconds for five minutes from a plateau identified as T in Figure 2 (T for transmission). To verify the reception of the packets, five different locations were established, identified as 1, 2, 3, 4, and 5 in Figure 2, marking the path and location of the receivers during the range test. Throughout the conducted trials, the distance between the transmitter (T) and the receivers was increased.

Figure 1: Peripheral towers and main tower responsible for acquiring soil-related and air-related variables, respectively.

Table 1 presents the approximate distances between the receiver and transmitters for each of the five tests. For all tests, the LoRa SX1276 devices were configured with a bandwidth of 125 kHz and a spreading factor of 7.

For the first and second trials, at locations R1 and R2, the receiver had no difficulty in receiving packets from the transmitter. For these two locations, the communication achieved an average RSSI of -111 dBm. In the following trial (location R3), the pattern from the previous two trials was maintained, with only a slight difference in the average RSSI of -113 dBm. As for location R4, at a distance of 4.20 km from the transmitter, difficulties were encountered in delivering some packets, with some packets being lost and others received with noise. However, approximately 90% of the packets were successfully received, with an average RSSI of -118 dBm. For the last trial, at 6.20 km (location R5) between both devices, again the receiver did not receive all the packets from the transmitter, receiving around 60% of the transmitted packets.

Based on the presented results of the five tests, it can be concluded that the SX1276 module presented a solid and consistent performance in the sum of all tests of the test, always maintaining a consistent average RSSI.

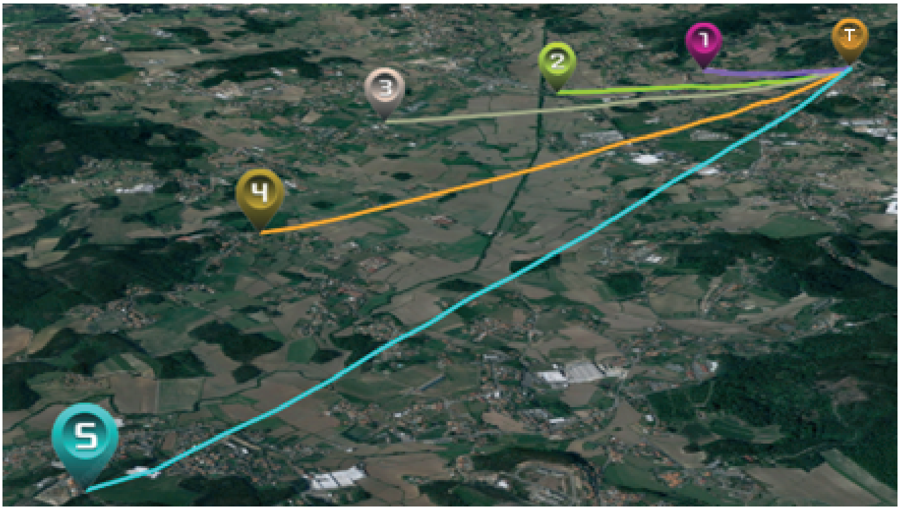

Figure 2: Mapping of range test communication points.

Table 1: Distance between modules for each test

Receiver ID	Distance between transmitter and received (km)	Difference between two successive locations (km)
R1	0.850	---
R2	1.740	+ 0.890
R3	2.740	+ 1.000
R4	4.200	+ 1.460
R5	6.200	+ 2.000

Results and Discussion

This work is part of a broader system for soil and air data monitoring for farm automation. The developed application aims to overcome the difficulties that some generations of farmers face in handling emerging technologies. Figure 3 shows a dashboard of the application, where the soil moisture acquired by two peripheral towers can be seen. The tools used for the web application included JavaScript, HTML, and CSS. In this application, it is possible to visualise real-time variations in soil humidity through a line graph. It is also possible to observe the current value using a gauge chart with relevant colours based on that value, making it easier to understand. The app allows the time scale to be adjusted, enabling the visualization of a specific time interval. With this user-friendly interface, it is easy to compare data from two different peripheral towers, placed at different locations, with specific time constraints.

Figure 3: App Dashboard

During the experimental tests with LoRa technology, a frame collision issue was identified, which involved some of the frames transmitted by the peripheral towers (PTs) not being received by the main tower (MT), resulting in a loss of approximately 4%. This problem was related to the interference caused by the radio signals emitted by the PTs. In the case of these experimental tests, frame collision occurred when both PTs were transmitting simultaneously, resulting in the loss of one of the frames.

The solution involved the development of a communication protocol between the MT and the PTs. This protocol was based on an acknowledgment frame mechanism (ACK Frames) in which the MT sends a signal to confirm the reception of the frames transmitted by the PTs. After receiving a frame, the MT should transmit an acknowledgment frame (ACK) within the next 10 seconds. If the ACK frame is not transmitted within the specified timeframe, the corresponding PT will retransmit it. This process will be repeated until the MT confirms its reception, as illustrated in Figure 4.

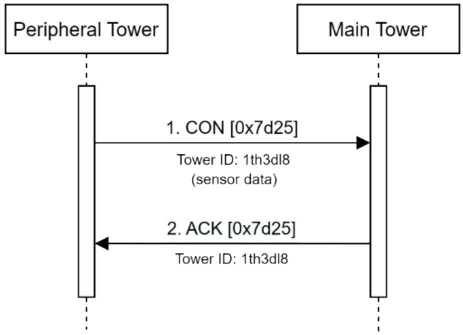

Figure 4: Communication protocol between peripheral towers and main tower.

After implementing the new communication model in the firmware of the two PTs, a LoRa communication test was conducted to verify if the implemented model would be able to solve the frame collision problem. In this test, two PTs were positioned to transmit data via LoRa to a single MT. At intervals of 15 seconds, each PT transmitted a set of sensor values for 58 hours, aiming to increase the probability of collisions. After data acquisition by the PTs and transmission to the MT, the MT forwarded it to a REST API for storage. The results obtained after 58 hours are presented in Table 2.

After the tests, it was observed that each of the two PTs transmitted approximately 11,000 frames, with no record of frame loss for both towers. However, it was found that out of the 11,003 frames sent by PT 1, 850 frames (7.41%) had the same header, indicating duplicated data. Similarly, out of the 10,898 frames transmitted by PT 2, 650 frames (5.96%) were also duplicates.

Based on the obtained results, it was necessary to review the implemented solution, leading to the conclusion that the data duplication was related to a failure in transmitting the acknowledgment frame. To avoid storing duplicate data, it was necessary to modify the firmware of the MT. The implemented changes made the MT start storing the ID of the last frame associated with the ID of the respective PT in non-volatile memory. With this modification, whenever an acknowledgment frame is not delivered and the PT resends it, the MT will check if the registered ID of the last frame matches the received ID. If it does, the storage of the data contained in the frame will be discarded, resulting in the transmission of only one acknowledgment frame, as shown in the sequence diagram of Figure 5. The established protocol aimed to improve the efficiency of communication between the MT and the PTs, reducing potential errors and loss of information.

Table 2: Number of transmitted, lost and duplicated frames, and test duration for both peripheral towers.

	Peripheral Tower 1	Peripheral Tower 2
Number of transmitted frames	11.003	10.898
Number of lost frames	0	0
Number of duplicated frames (%)	815 (7.4%)	650 (6.0%)
Test duration	58:09:11	58:07:32

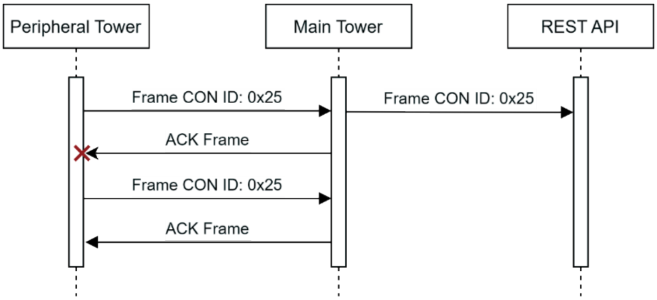

Figure 5: The same frame is sent twice but only one frame is forwarded to the server.

4. Conclusions

This work presents a robust and effective data acquisition system for soil and air data monitoring. The system allows the visualisation of real-time variations in soil humidity using a line graph. It is also possible to observe the current value using a gauge chart with relevant colours, in addition to making it possible to use a time scale to be adjusted, enabling the visualization of a specific time interval, allowing farmers to have a better understanding of the type of soil available for their crops.

The best results for a sending frequency of six sets of data per hour were achieved with LiPo 3.7 V 1350 mA batteries. Data from the two PTs were sent to the MT at the frequency of 868 MHz. During the tests, it was found that the initial implemented solutions could not completely solve the issue of collisions. However, by using an acknowledgment frame (ACK Frame) protocol, the PTs can determine if the transmitted frames were received by the MT, enabling them to continue reading and sending new sensor data. Although it does not prevent collisions, the developed protocol ensures that if frame collisions or even data failures occur (due to payload corruption or loss of the transmitted frame, for example), they will be retransmitted until the respective PT receives an ACK Frame from the

MT. The success rate of the data transmitted was 100%. However, between 6% and 7.4% of the transmitted frames needed to be resent by the peripheral towers. Thus, by dealing with the data loss issues, improved potential for the specific applications is demonstrated.

References

1. Pathmudi VR, Khatri N, Kumar S, et al (2023) A systematic review of IoT technologies and their constituents for smart and sustainable agriculture applications. Sci Afr 19:e01577. https://doi.org/10.1016/j.sciaf.2023.e01577

2. Jabbar WA, Subramaniam T, Ong AE, et al (2022) LoRaWAN-Based IoT System Implementation for Long-Range Outdoor Air Quality Monitoring. Internet of Things 19:100540. https://doi.org/10.1016/j.iot.2022.100540

3. Soori M, Arezoo B, Dastres R (2023) Internet of things for smart factories in industry 4.0, a review. Internet of Things and Cyber-Physical Systems. https://doi.org/10.1016/j.iotcps.2023.04.006

4. Haxhibeqiri J, De Poorter E, Moerman I, Hoebeke J (2018) A Survey of LoRaWAN for IoT: From Technology to Application. Sensors 18:3995. https://doi.org/10.3390/s18113995

5. Barot V, Kapadia V (2020) Air Quality Monitoring Systems using IoT: A Review. In: 2020 International Conference on Computational Performance Evaluation (ComPE). IEEE, pp 226–231

6. Erfaniangolabforoushanahlyazd B, Zhang X, Arslan M (2021) A Smart Parking System Based on Lorawan Technology. In: 2021 18th International Computer Conference on Wavelet Active Media Technology and Information Processing (ICCWAMTIP). IEEE, pp 625–629

7. Chaurasia N, Kumar P (2023) A Comprehensive Study on Issues and Challenges Related to Privacy and Security in IoT. e-Prime - Advances in Electrical Engineering, Electronics and Energy 100158. https://doi.org/10.1016/j.prime.2023.100158

8. Keshta I (2022) AI-driven IoT for smart health care: Security and privacy issues. Inform Med Unlocked 30:100903. https://doi.org/10.1016/j.imu.2022.100903

9. Sarkar NI, Iasepi LS, Gul S (2021) Designing a Smart City: Technologies, Challenges and Solutions. pp 51–70

10. Miles B, Bourennane E-B, Boucherkha S, Chikhi S (2020) A study of LoRaWAN protocol performance for IoT applications in smart agriculture. Comput Commun 164:148–157. https://doi.org/10.1016/j.comcom.2020.10.009

11. Sun Z, Yang H, Liu K, et al (2022) Recent Advances in LoRa: A Comprehensive Survey. ACM Trans Sens Netw 18:1–44. https://doi.org/10.1145/3543856

12. Citoni B, Fioranelli F, Imran MA, Abbasi QH (2019) Internet of Things and LoRaWAN-Enabled Future Smart Farming. IEEE Internet of Things Magazine 2:14–19. https://doi.org/10.1109/IOTM.0001.1900043

13. Paul R, Bin Nazir J (2023) IoT-Based Smart Office and Parking System with the Implementation of LoRa. pp 317–330

14. Bembe M, Abu-Mahfouz A, Masonta M, Ngqondi T (2019) A survey on low-power wide area networks for IoT applications. Telecommun Syst 71:249–274. https://doi.org/10.1007/s11235-019-00557-9

15. Jo J, Jo B, Kim J, et al (2020) Development of an IoT-Based Indoor Air Quality Monitoring Platform. J Sens 2020:1–14. https://doi.org/10.1155/2020/8749764

16. Chen Q, Wang J (2023) AlignTrack: Push the SNR Limit of LoRa Collision Decoding. IEEE/ACM Transactions on Networking 1–16. https://doi.org/10.1109/TNET.2023.3235041